Metallic Ground State of Ultrathin Films of Metals

Allen M. Goldman, University of Minnesota, DMR-0138209

Superconductor-insulator (SI) transitions in ultrathin (two-dimensional (2D)) films are the most fundamental of quantum phase transitions (QPTs). QPTs are transitions between quantum mechanical ground states controlled by parameters such as disorder or magnetic field rather than temperature. A complication is that QPTs occur at zero temperature, whereas data is acquired down to the lowest accessible temperature. A scaling analysis is used to infer behavior at zero temperature. Success with this is evidence of, but not a proof of a QPT, as other physics can intervene at lower temperatures. We have found a metallic ground state for a system hitherto believed to be superconducting and to exhibit an SI transition. We have been able to prove that this observation is not an artifact produced by the electrons of the film not being cooled. The existence of a metallic ground state is an important challenge to theory, which predicts that it should not occur. It may also have implications for the operation of superconducting realizations of quantum computers.

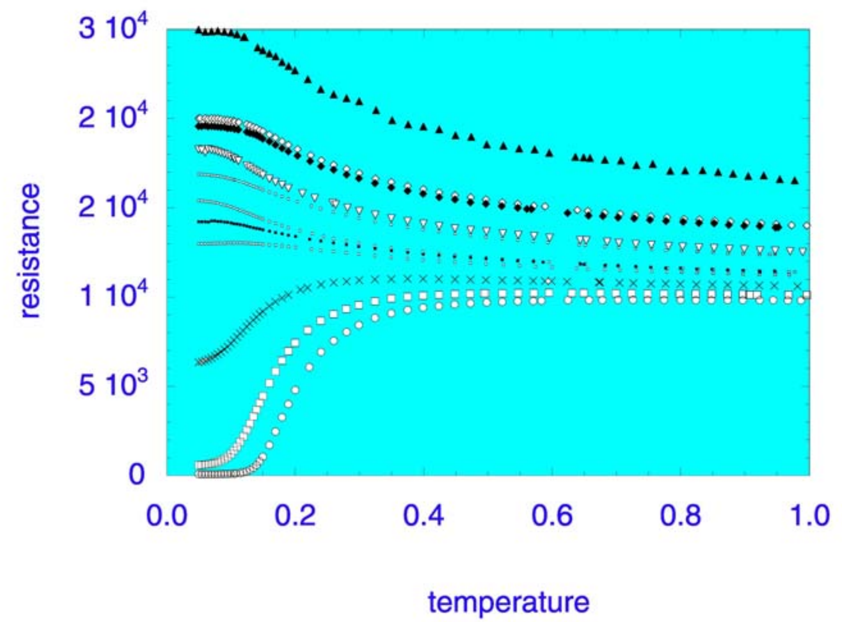

Fig. 1. Evolution of the sheet resistance, R(T), for a series of eleven different films of amorphous Bi of different thicknesses. Increasing thickness corresponds to decreasing disorder. From top to bottom, thickness are: 8.5, 8.7, 8.8, 8.85, 8.91, 8.99, 9.05, 9.09, 9.19, 9.25, and 9.3 Å. The resistance at a temperature of 50mK of the film separating those that appear insulating from those that appear to be superconducting a high temperatures is very close to 12,900 Ω, or twice the quantum resistance for pairs. The low temperature behavior of all films is seen to be metallic, i.e., not changing with temperature. In this regime the magneto-resistance,which is not shown does change, which demonstrates that the films are cooling.

Graduate Student Luis Hernandez was awarded a Graduate Dissertation Fellowship by the Graduate School of the University of Minnesota.

Professor Allen Goldman Goldman will receive the Fritz London Memorial Prize for Low Temperature Physics at the 23rd International Conference on Low Temperature Physics which will be held in Hiroshima Japan in August 2002. He will be cited "for his contribution to the physics of superconductors, particularly the discovery of the gapless collective modes, and for his inventive work on superconductor-insulator transitions in ultrathin films." This award, which will be shared with Professor Russell Donnelly of Oregon State University and Professor Walter Hardy of the University of British Columbia is given every three years and is intended to recognize outstanding experimental and theoretical contributions to low temperature physics. A previous recipient of this award was the late William Fairbank, who was Goldman's doctoral mentor at Stanford University. Some of the other winners have been important historical figures in physics, including several Nobel Prize winners.

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Education and Outreach

The participants in this work included:

2 summer undergraduates: Jamie O'Brien, Pomona College, California, Thongphanh Phantharady, Allbertson College, Idaho

3 graduate students: Luis Hernandez, Melissa Eblen (NSF Pre-doctoral Fellow), and Kevin Parendo (Part-time Teaching Assistant)

1 post-doc: Anand Bhattacharya

Dr. Bhattacharya is a performer for one team of the *Physics Force*, a Physics Department outreach activity that demonstrates physics principles for the general population and K through 12. During the 2001-2002 academic year the *Force* played to more than 40,000 people.

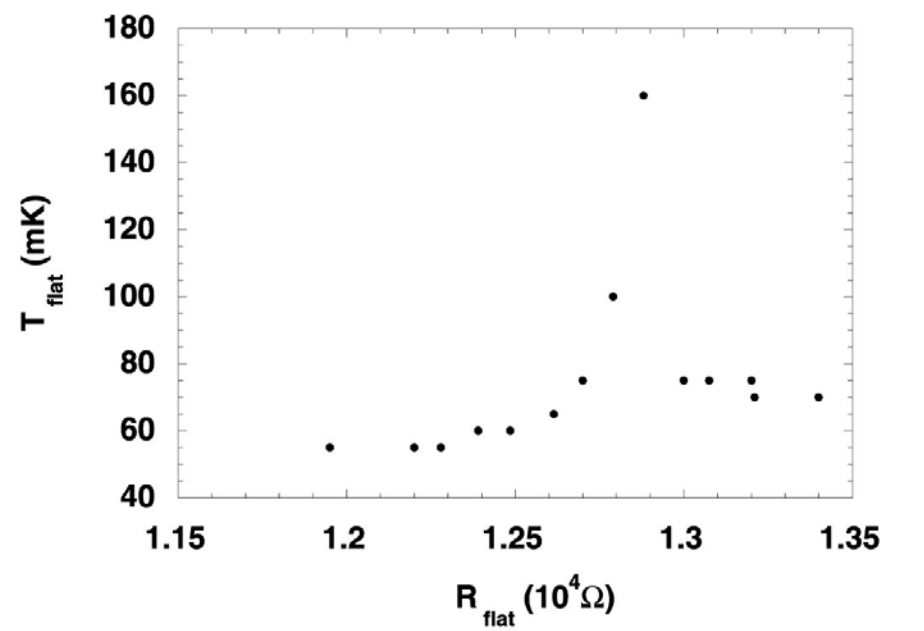
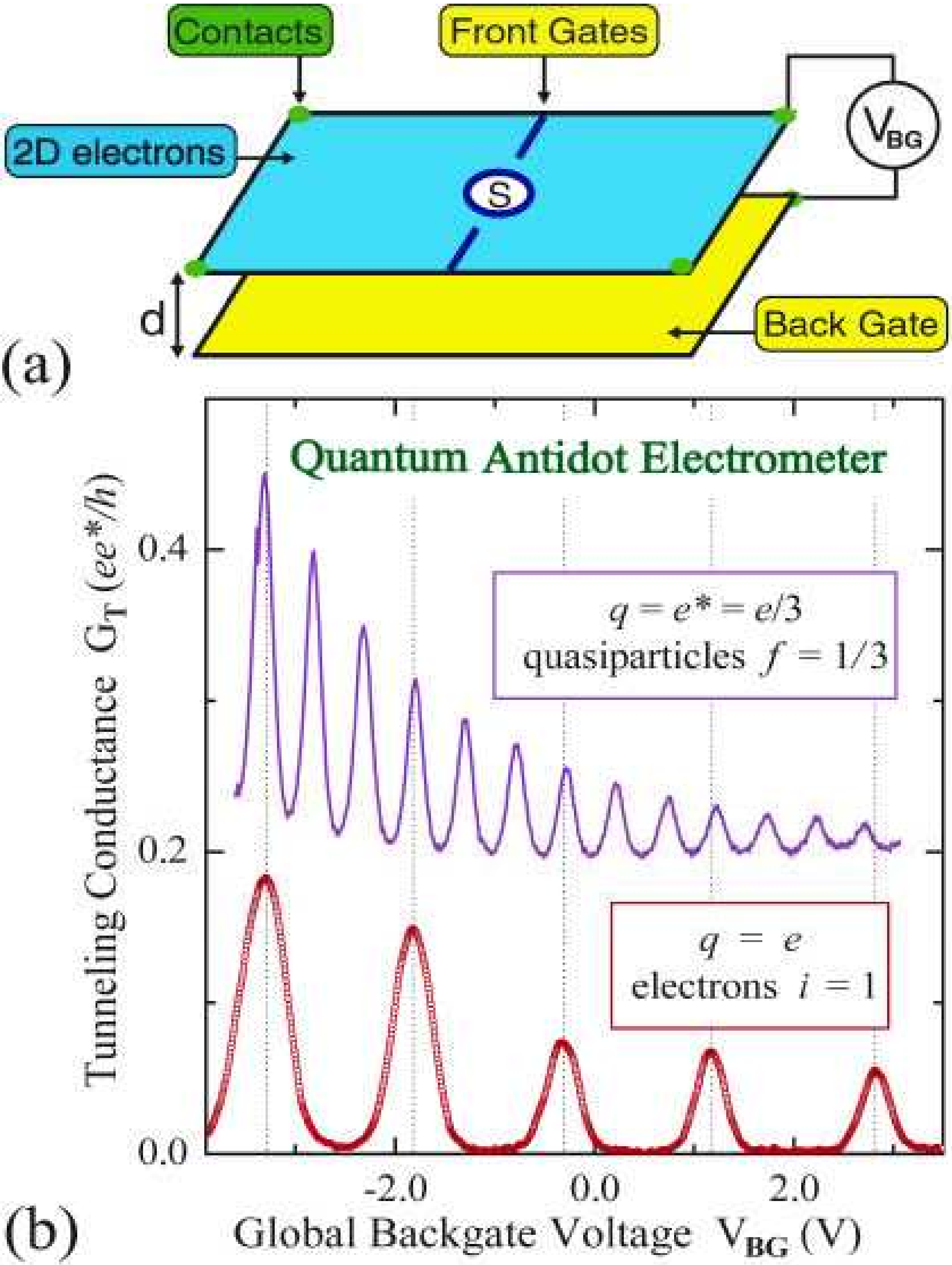


Fig. 2. Plot ot he f temperature of onset of the metallic regime, T_{flat} , as a function of the low temperature sheet resistance of that regime R_{flat}.. The data is from the magnetic field dependence of the 9.09Å thick film of Fig. 1.. The striking feature is the peak found at a sheet resistance R_{flat} that is very close to 12,900 Ω, which is twice the quantum resistance for electron pairs, $h/2e^2$. Whether this is a signature of some new universality is not known.



(a) Quantum Antidot of area S can be populated either by electrons or by Laughlin quasiparticles. The particles are attracted by the electric field proportional to the voltage applied to the back gate, which forms a parallel plate capacitor with the 2D electrons. The change in the number of particles is monitored by tunneling between the two front gates via the antidot: change by one particle is seen as a peak in tunneling conductance.

(b) It takes the same electric field to attract one electron as three Laughlin quasiparticles; thus the charge of each quasiparticle is e* = e/3.

The experiment is conducted in very strong magnetic fields and at a very low temperature, so that two-dimensional electrons condense into new states of matter: integer (i = 1) or fractional (f = 1/3) quantum Hall liquids. The quantum numbers i or f label the quantum Hall states.